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(54) **ROPE STRUCTURE WITH IMPROVED BENDING FATIGUE AND ABRASION RESISTANCE CHARACTERISTICS**

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This patent is subject to a terminal disclaimer.

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**D02G 3/36** (2006.01)

(52) **U.S. Cl.** ..... **57/237; 57/241; 57/258**

(58) **Field of Classification Search** ..... **57/223, 57/237, 241, 258**

See application file for complete search history.

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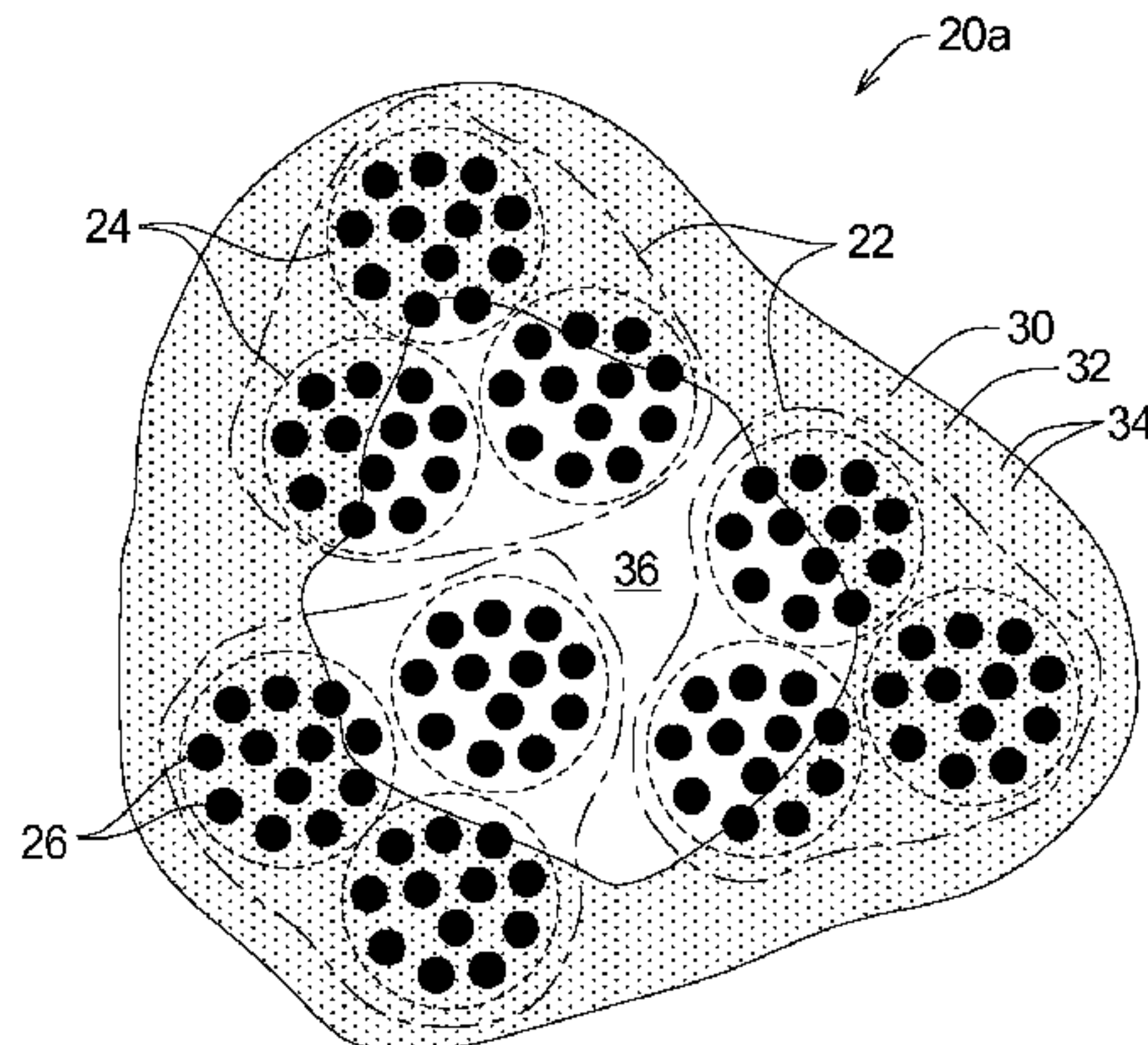
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(57) **ABSTRACT**

A rope structure adapted to engage an external structure comprising a primary strength component and a coating. The primary strength component comprises a plurality of fibers. The coating comprises a lubricant portion and a binder portion that fixes the lubricant portion relative to at least some of the fibers. The coating is applied to the primary strength component such that the lubricant portion reduces friction between adjacent fibers and reduces friction between fibers and the external structure.

**18 Claims, 4 Drawing Sheets**



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FIG. 1A

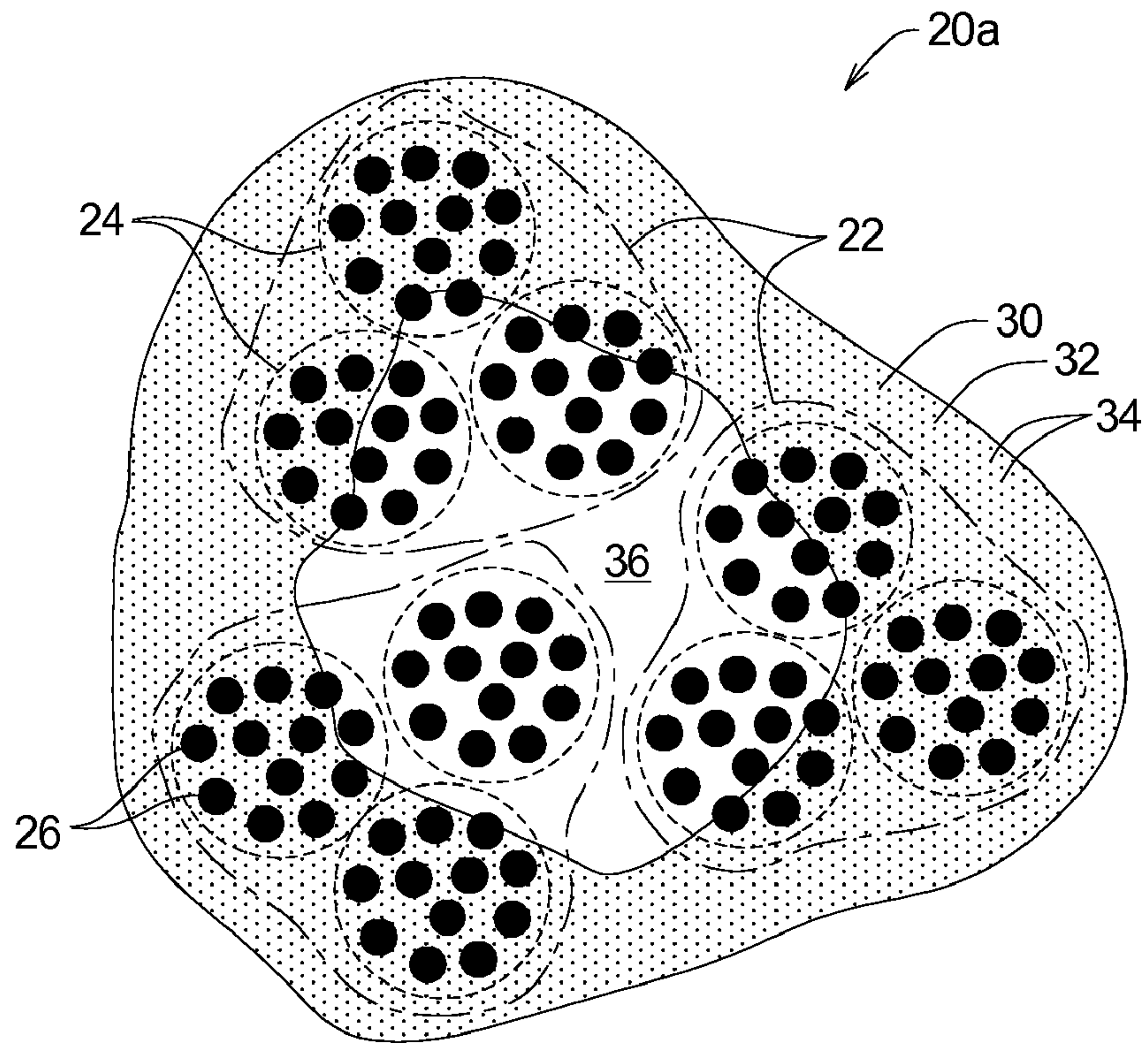


FIG. 1B

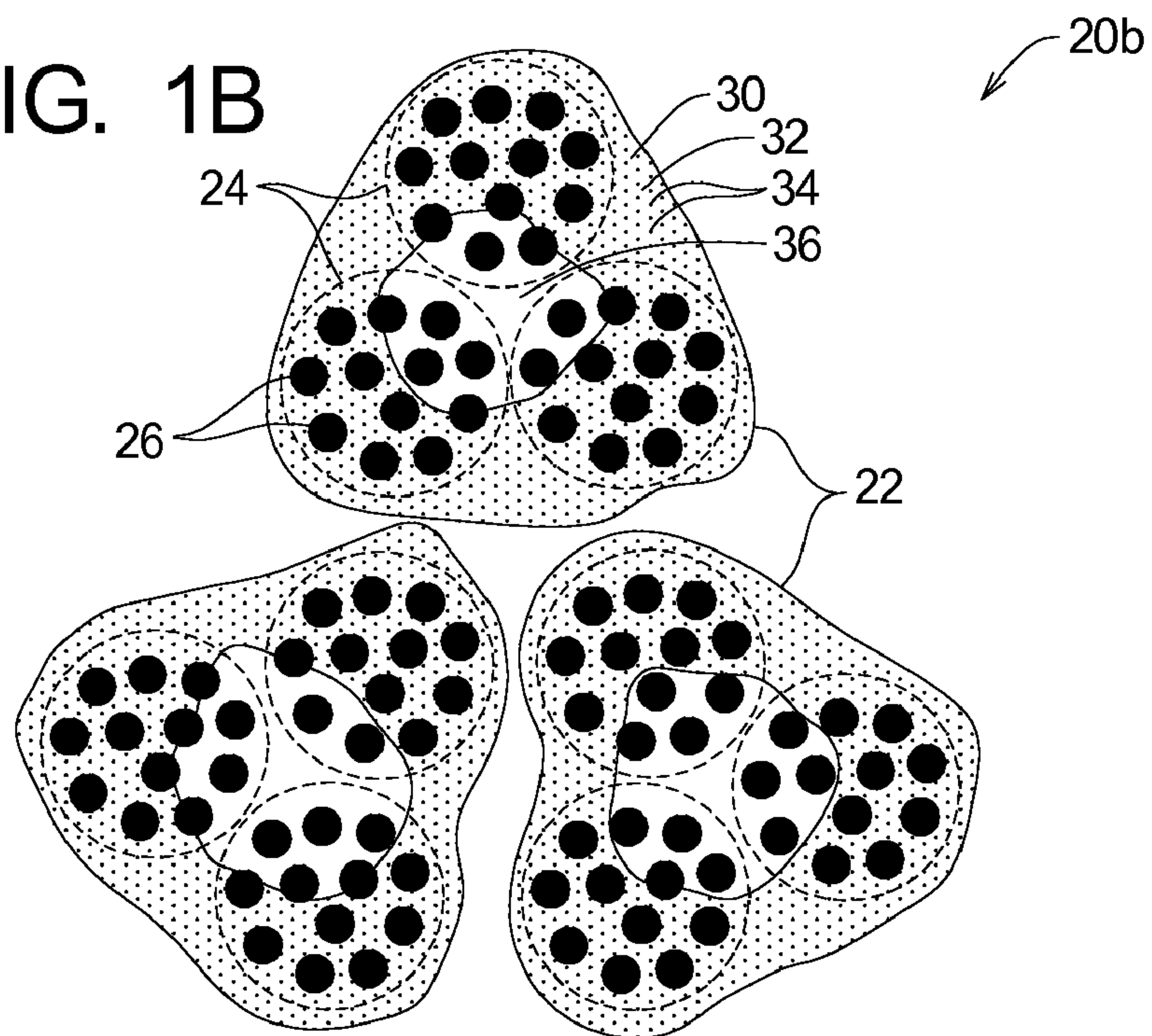


FIG. 2

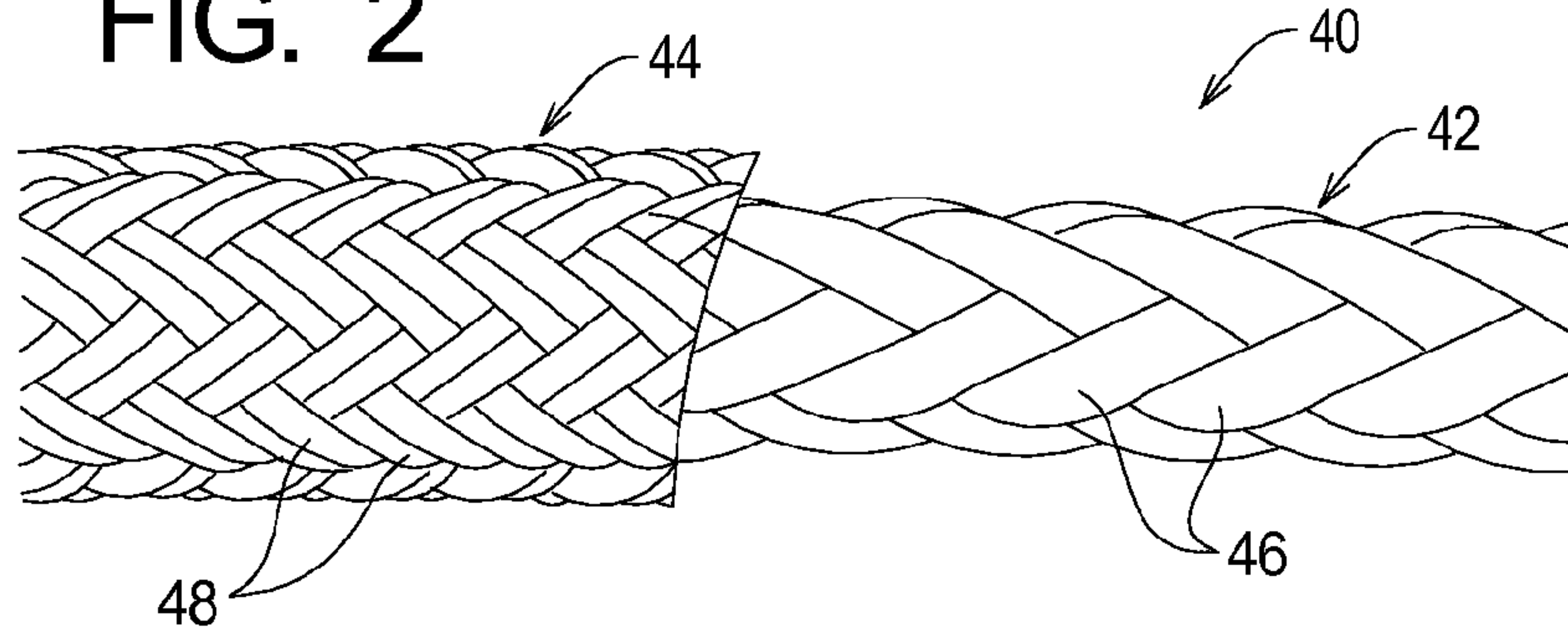


FIG. 3

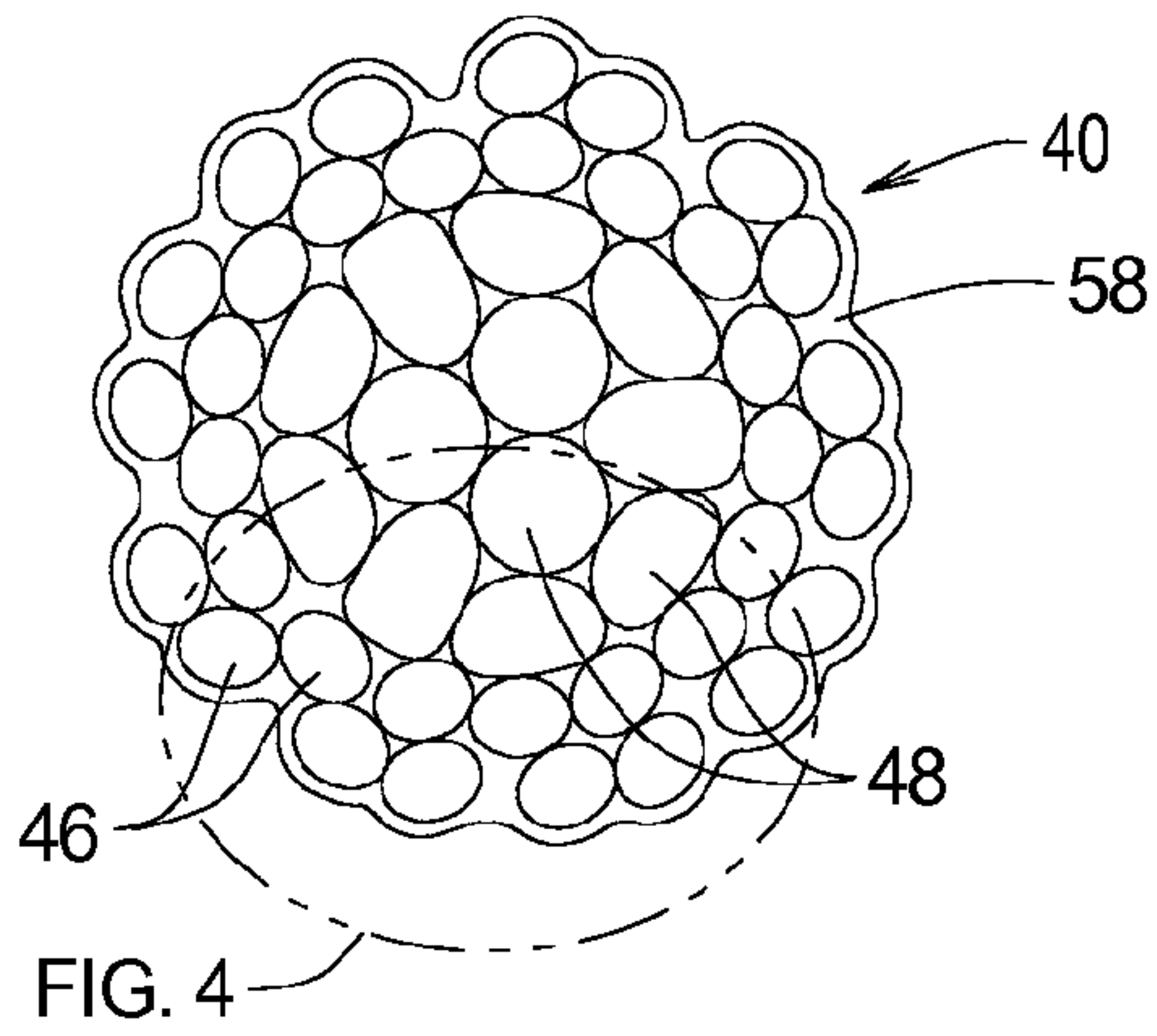


FIG. 4

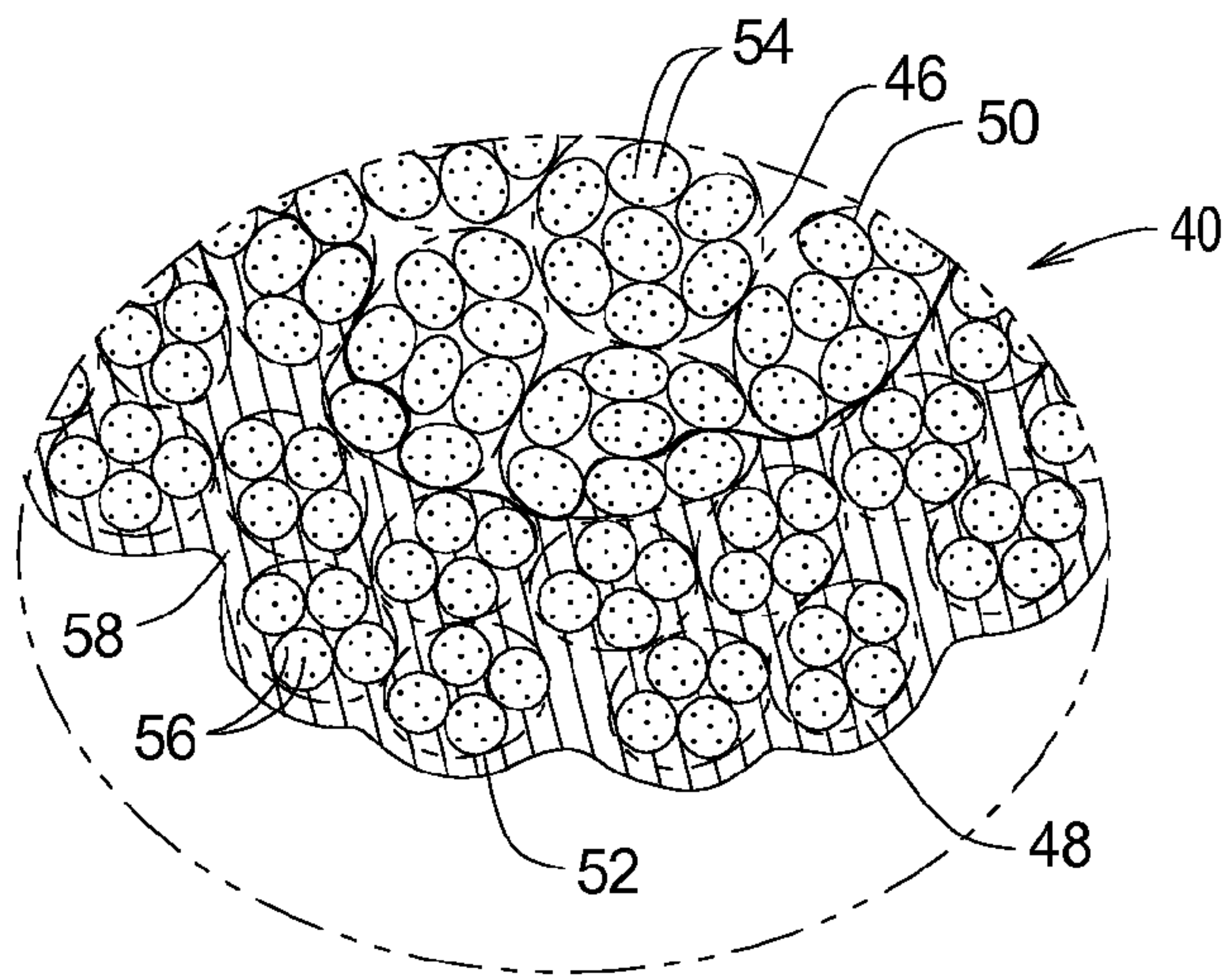


FIG. 5

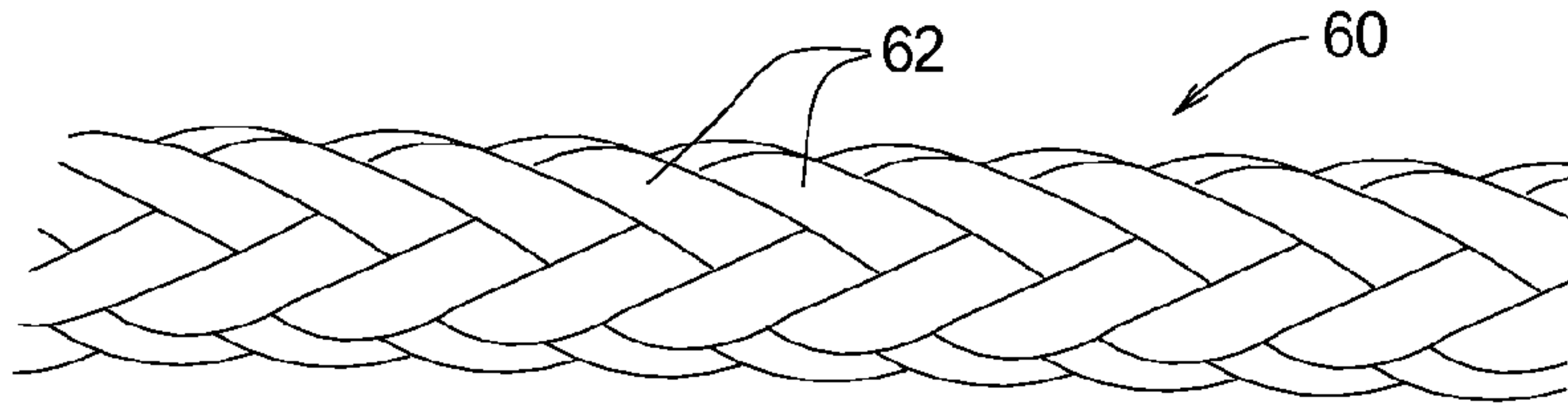


FIG. 6

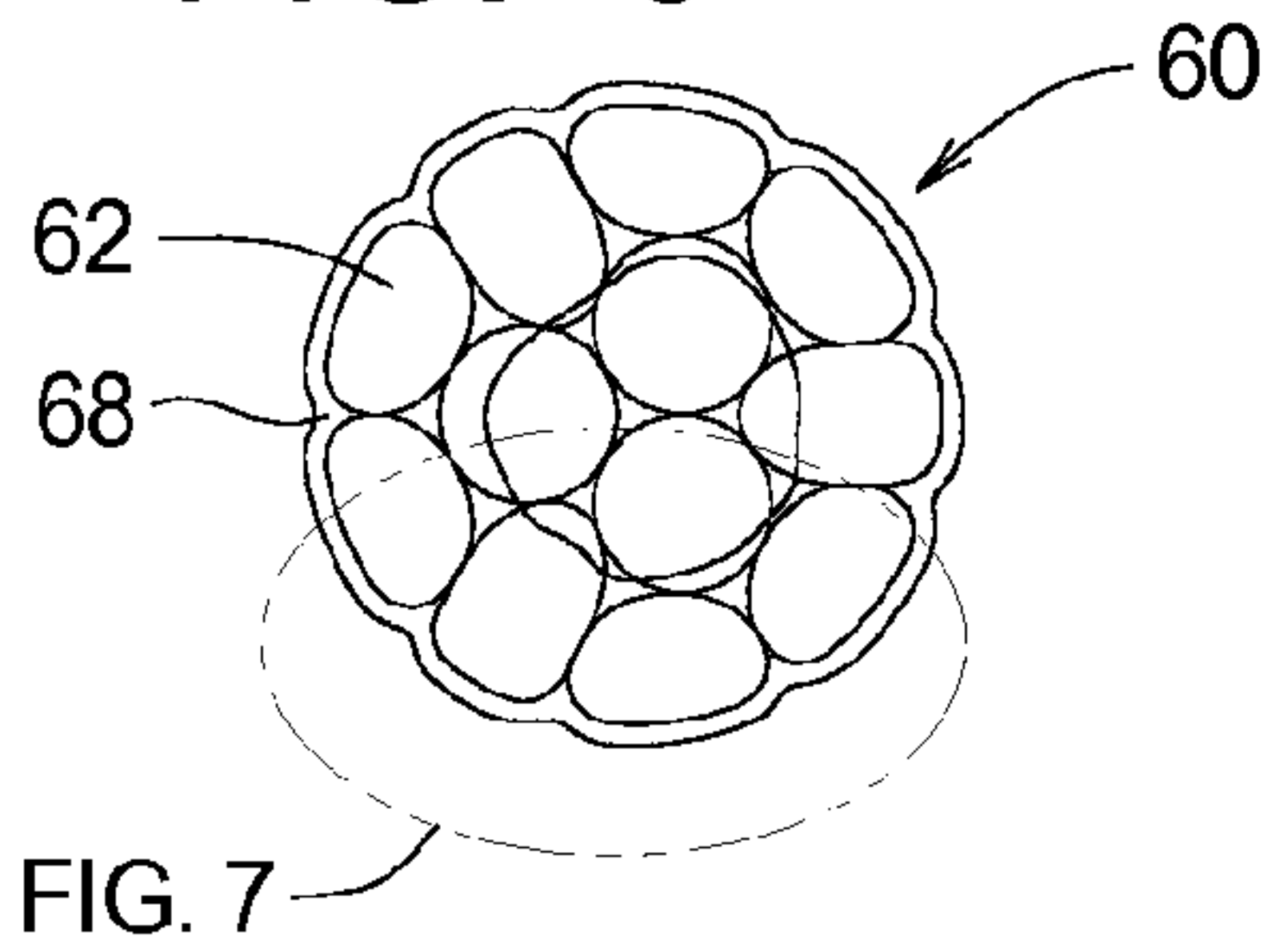


FIG. 7

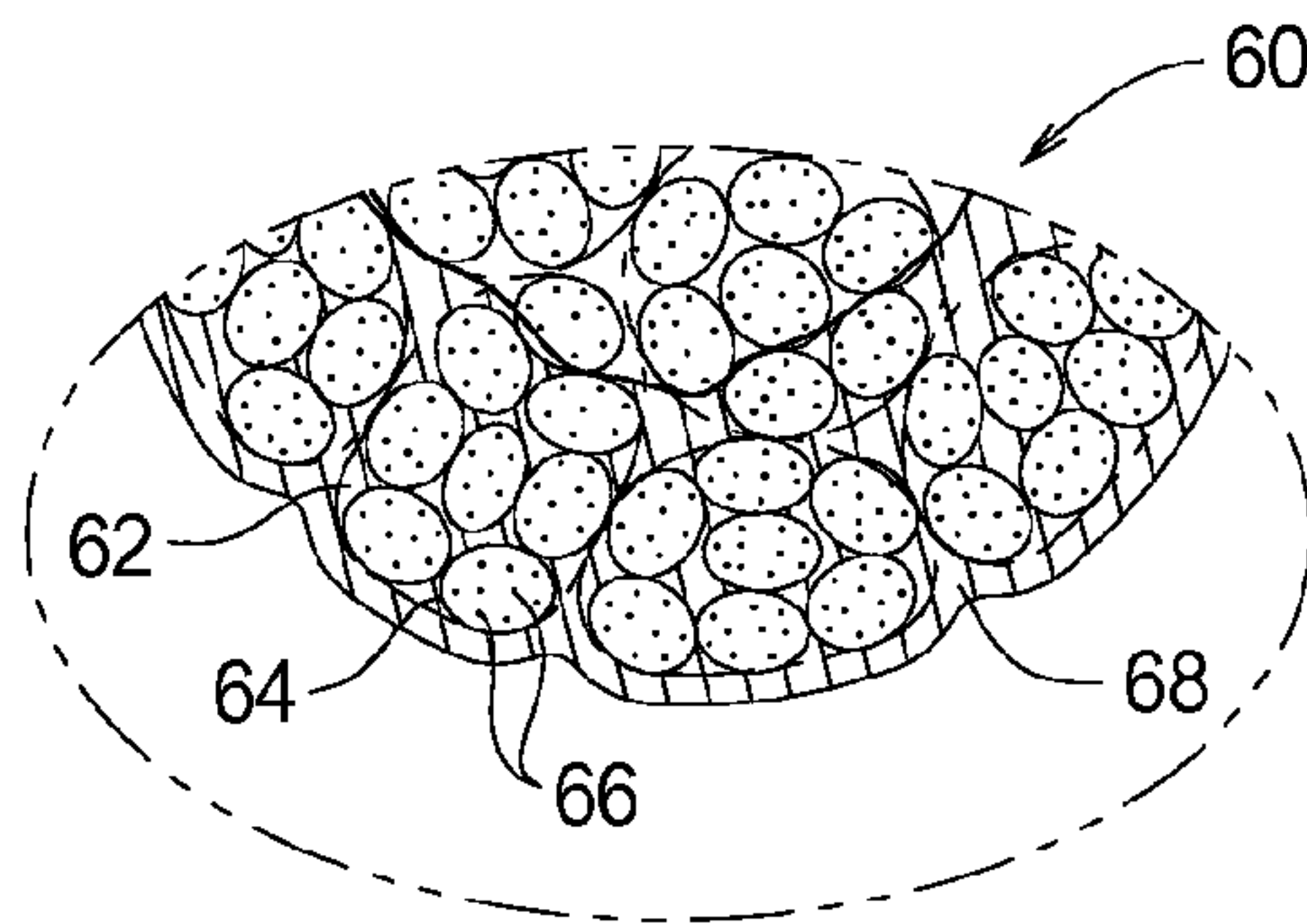


FIG. 8

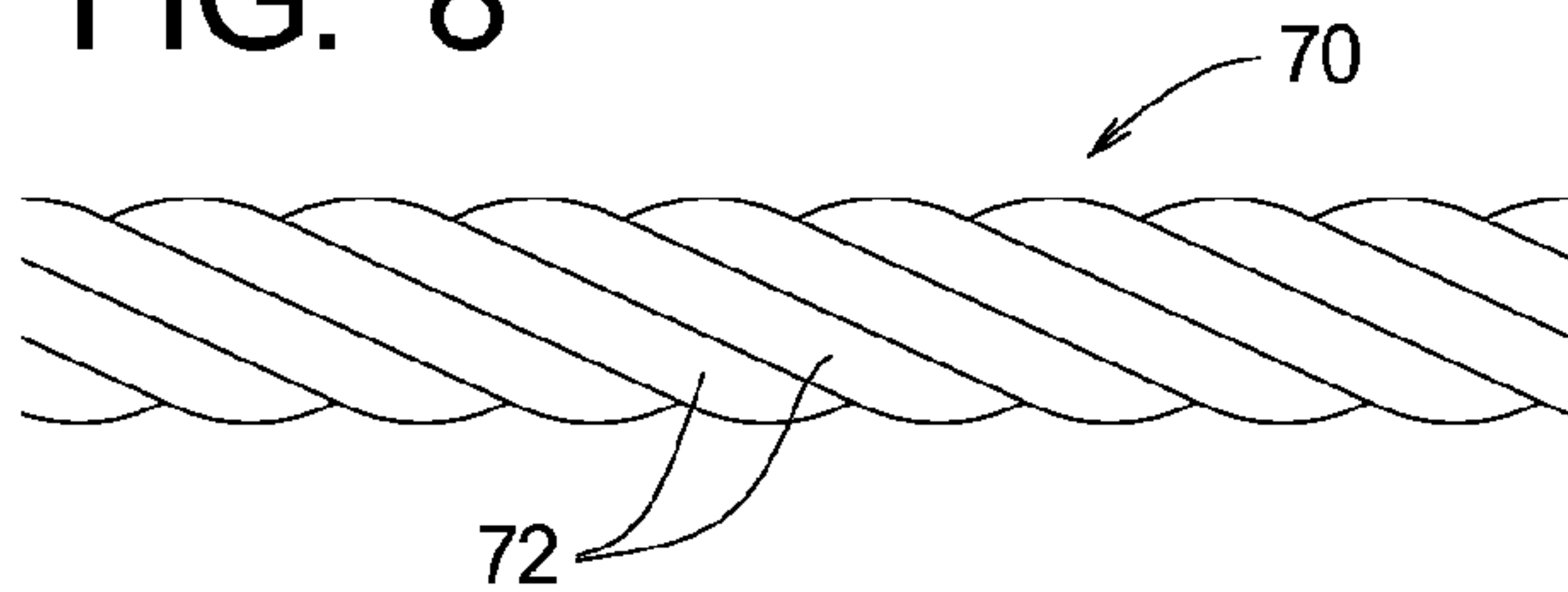


FIG. 9

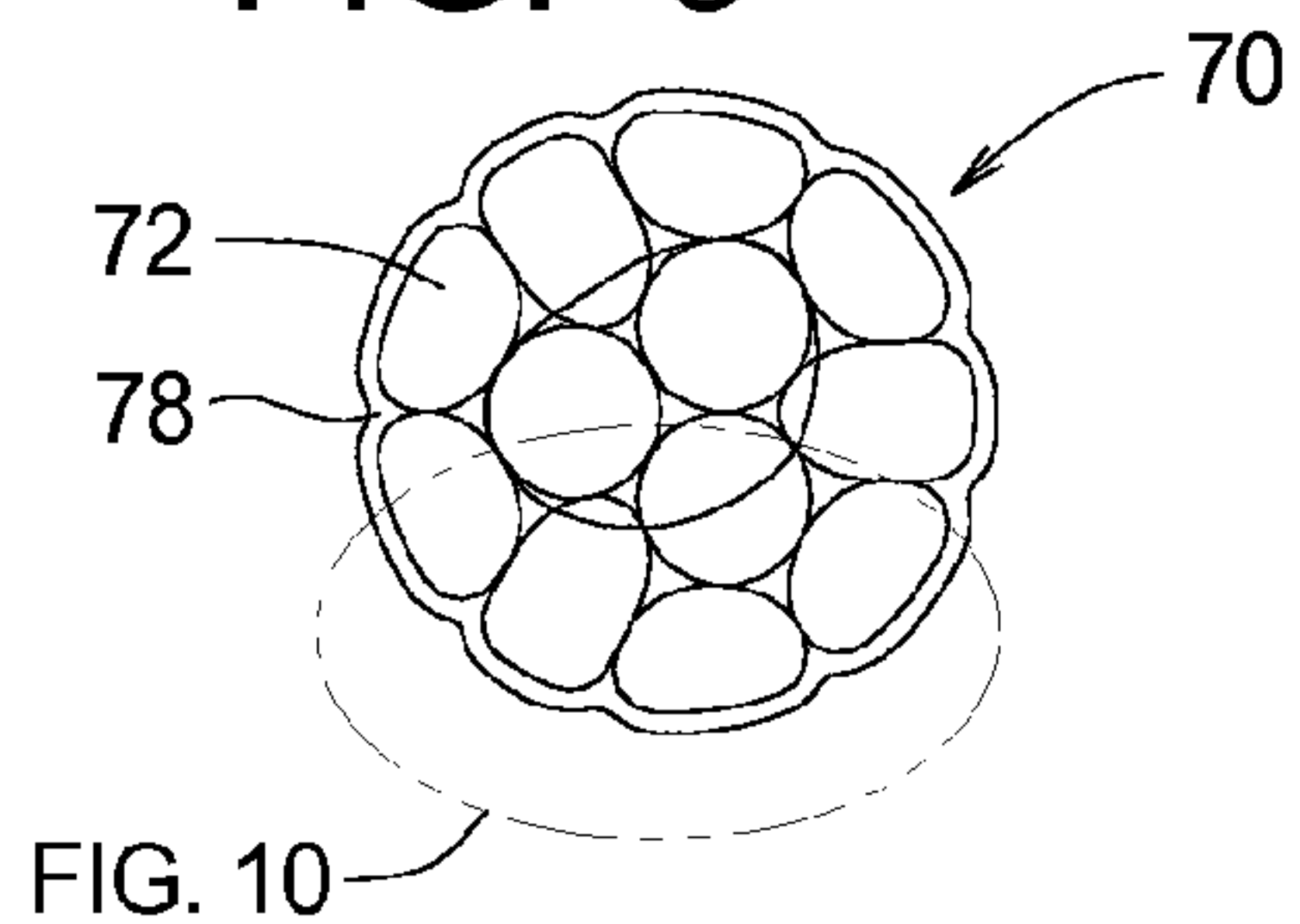


FIG. 10

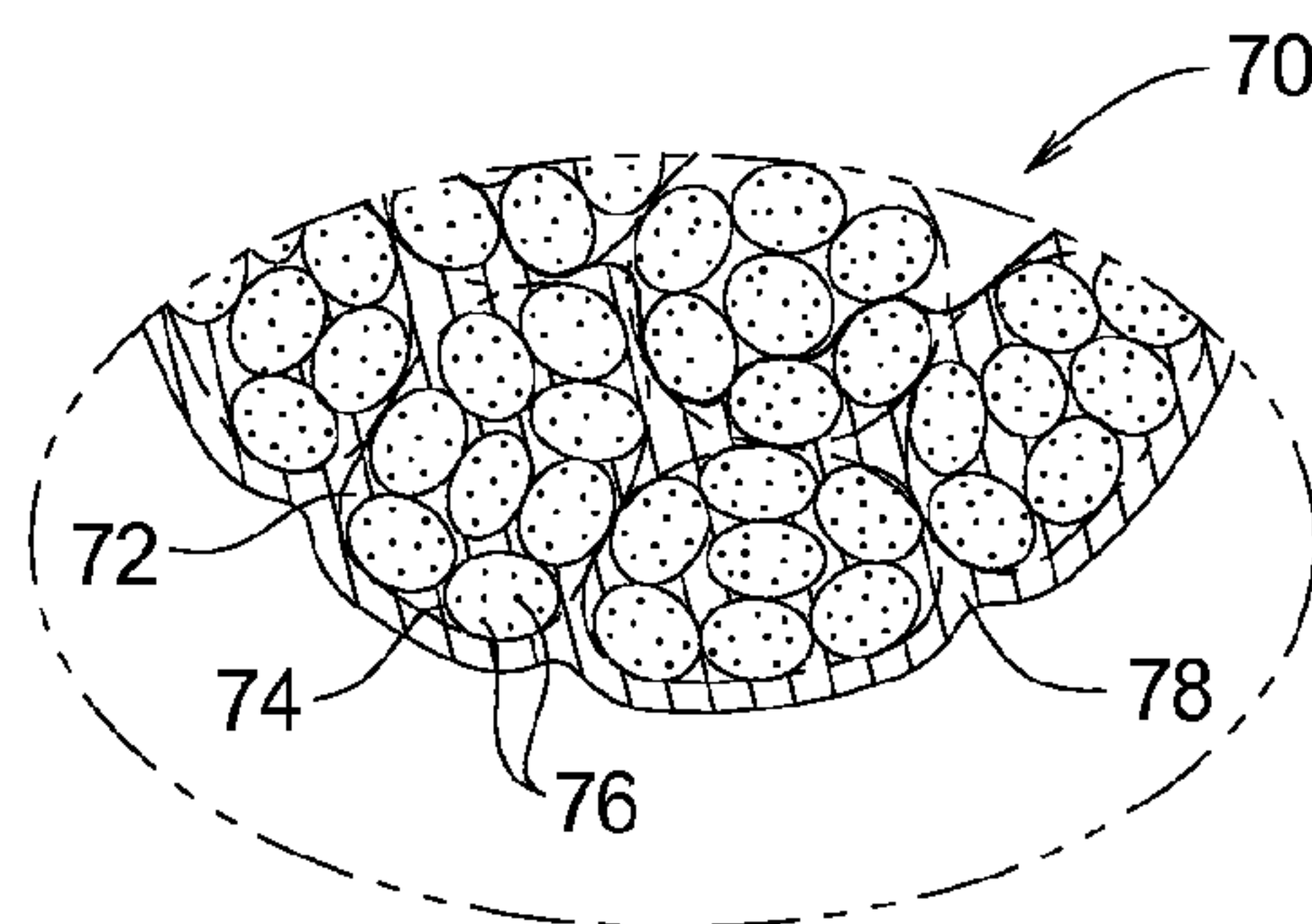




FIG. 11

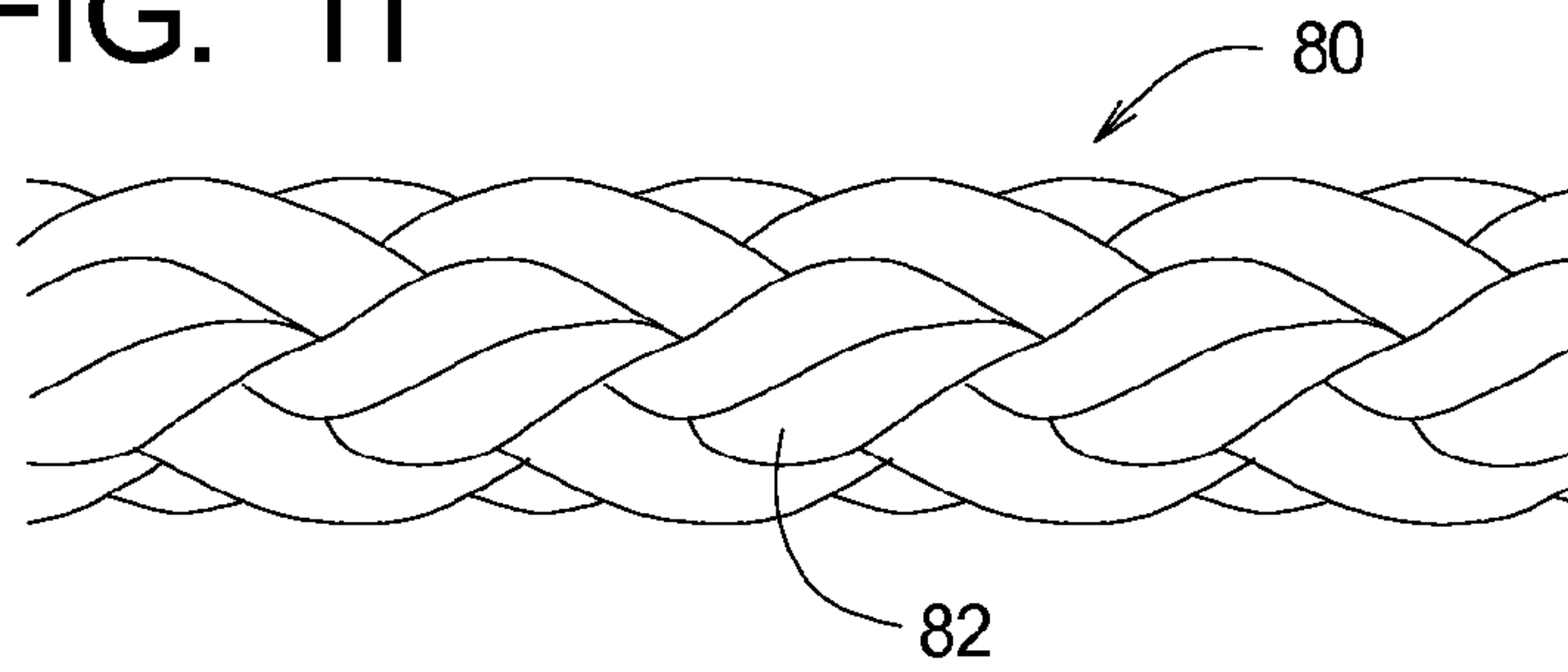


FIG. 12

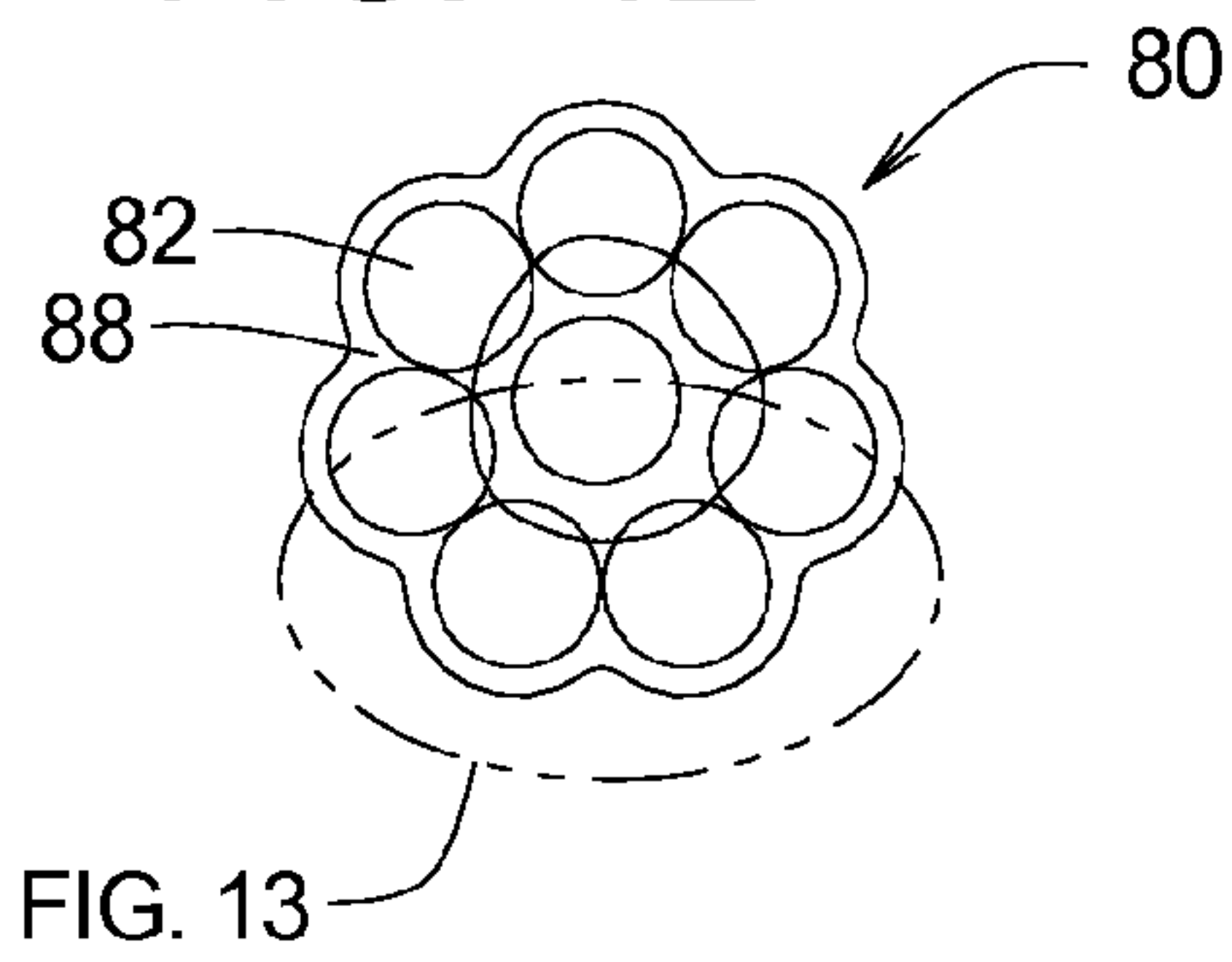
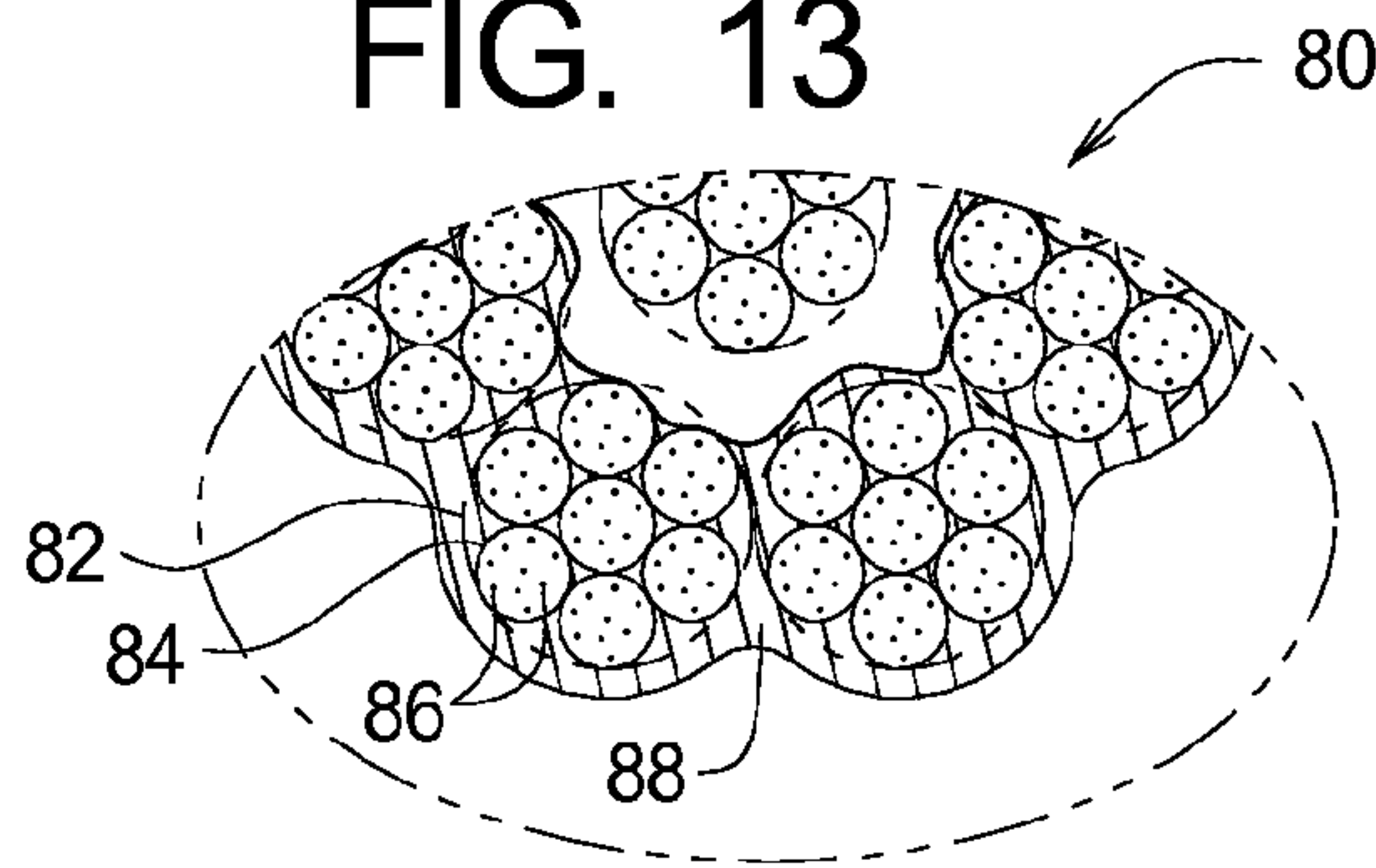


FIG. 13



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## ROPE STRUCTURE WITH IMPROVED BENDING FATIGUE AND ABRASION RESISTANCE CHARACTERISTICS

### RELATED APPLICATIONS

This application, U.S. patent application Ser. No. 12/776,958, is a continuation-in-part of U.S. patent application Ser. No. 11/522,236 filed Sep. 14, 2006, now U.S. Pat. No. 7,739,863, which issued on Jun. 22, 2010.

U.S. patent application Ser. No. 11/522,236 claims benefit of U.S. Provisional Patent Application Ser. No. 60/717,627 filed Sep. 15, 2005.

The subject matter of the foregoing related applications are incorporated herein by reference.

### TECHNICAL FIELD

The present invention relates to rope systems and methods and, in particular, to ropes that are coated to improve the resistance of the rope to bending fatigue.

### BACKGROUND

The characteristics of a given type of rope determine whether that type of rope is suitable for a specific intended use. Rope characteristics include breaking strength, elongation, flexibility, weight, bending fatigue resistance and surface characteristics such as abrasion resistance and coefficient of friction. The intended use of a rope will determine the acceptable range for each characteristic of the rope. The term "failure" as applied to rope will be used herein to refer to a rope being subjected to conditions beyond the acceptable range associated with at least one rope characteristic.

The present invention relates to ropes that are commonly referred to in the industry as "lift lines". Lift lines are used to deploy (lower) or lift (raise) submersible equipment used for deep water exploration. Bending fatigue and abrasion resistance characteristics are highly important in the context of lift lines.

In particular, a length of lift line is connected at a first end to an on-board winch or capstan and at a second end to the submersible equipment. Between the winch and the submersible equipment, the lift line passes over or is wrapped around one or more intermediate structural members such as a closed chock, roller chock, bollard or bit, staple, bullnose, cleat, a heave compensating device, or a constant tensioning device.

When loads are applied to the lifting line, the lifting line wraps around such intermediate structural members and is thus subjected to bending fatigue and abrasion at the intermediate structural members. Abrasion and heat generated by friction at the point of contact between the lifting line and the intermediate structural members can create wear on the lifting line that can affect the performance of the lifting line and possibly lead to failure thereof.

The need thus exists for improved ropes for use as lifting lines that have improved bending fatigue and abrasion resistance characteristics.

### SUMMARY

The present invention may be embodied as a rope structure adapted to engage an external structure comprising a primary strength component and a coating. The primary strength component comprises a plurality of fibers. The coating comprises a lubricant portion and a binder portion that fixes the lubricant portion relative to at least some of the fibers. The coating is

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applied to the primary strength component such that the lubricant portion reduces friction between adjacent fibers and reduces friction between fibers and the external structure.

The present invention may also be embodied as a method of forming a rope structure adapted to engage an external structure comprising the following steps. A plurality of fibers is provided. The plurality of fibers is combined to form a primary strength component. A coating material comprising a lubricant portion and a binder portion is provided in liquid form. The coating material is applied in liquid form to the primary strength component. The coating material in liquid form is allowed to dry on the primary strength member to form a coating such that the lubricant portion is adhered to at least some of the fibers to reduce friction between adjacent fibers and to reduce friction between fibers and the external structure.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic cut-away view of a rope constructed in accordance with, and embodying, the principles of the present invention;

FIG. 2 is a side elevation view of a first example of a rope of the present invention;

FIG. 3 is a radial cross-section of the rope depicted in FIG. 2;

FIG. 4 is a close-up view of a portion of FIG. 3;

FIG. 5 is a side elevation view of a second example of a rope of the present invention;

FIG. 6 is a radial cross-section of the rope depicted in FIG. 5;

FIG. 7 is a close-up view of a portion of FIG. 6;

FIG. 8 is a side elevation view of a third example of a rope of the present invention;

FIG. 9 is a radial cross-section of the rope depicted in FIG. 8;

FIG. 10 is a close-up view of a portion of FIG. 9;

FIG. 11 is a side elevation view of a fourth example of a rope of the present invention;

FIG. 12 is a radial cross-section of the rope depicted in FIG. 8; and

FIG. 13 is a close-up view of a portion of FIG. 12.

### DETAILED DESCRIPTION

Referring initially to FIGS. 1A and 1B of the drawing, depicted in cross-section therein are rope structures 20a and 20b constructed in accordance with, and embodying, the principles of the present invention. The rope structures 20a and 20b are each formed by one or more plies or strands 22. The plies or strands 22 are formed by one or more yarns 24. The yarns 24 are formed by a plurality of fibers 26. By way of example, the fibers 26 may be twisted together to form the yarns, the yarns 24 twisted to form the plies or to strands 22, and the strands 22 braided or twisted to form the rope structure 20a or 20b.

In addition, the example rope structures 20a and 20b each comprises a coating 30 that is applied either to the entire rope structure (FIG. 1A) or to the individual strands (FIG. 1B). In the example ropes 20a and 20b, coating material is applied in liquid form and then allowed to dry to form the coating 30. The coating 30 comprises a binder portion 32 (solid matrix) and a lubricant portion 34 (e.g., suspended particles). The binder portion 32 adheres to or suspends the fibers 26 to hold the lubricant portion 34 in place adjacent to the fibers 26. More specifically, the coating 30 forms a layer around at least some of the fibers 26 that arranges the lubricant portion 34



between at least some of the adjacent fibers 26 and between the fibers 26 and any external structural members in contact with the rope structure 20a or 20b.

The fibers 26 are combined to form the primary strength component of the rope structures 20a and 20b. The lubricant portion 34 of the coating 30 is supported by the binder portion to reduce friction between adjacent fibers 26 as well as between the fibers 26 and any external structural members in contact with the rope structure 20a or 20b. The lubricant portion 34 of the coating 30 thus reduces fatigue on the fibers 26 when the rope structures 20a or 20b are bent around external structures. Without the lubricant portion 34 of the coating 30, the fibers 26 would abrade each other, increasing bending fatigue on the entire rope structure 20. The lubricant portion 34 of the coating 30 further reduces friction between the fibers 26 and any external structural members, thereby increasing abrasion resistance of the rope structures 20a and 20b.

With the foregoing understanding of the basic construction and characteristics of the rope structure 20 of the present invention in mind, the details of construction and composition of the blended yarn 20 will now be described.

In the liquid form, the coating material comprises at least a carrier portion, the binder portion, and the lubricant portion. The carrier portion maintains the liquid form of the coating material in a flowable state. However, the carrier portion evaporates when the wet coating material is exposed to the air, leaving the binder portion and the lubricant portion to form the coating 30. When the coating material has dried to form the coating 30, the binder portion 32 adheres to the surfaces of at least some of the fibers 26, and the lubricant portion 34 is held in place by the binder portion 32. The coating material is solid but not rigid when dried as the coating 30.

In the example rope structures 20a and 20b, the coating material is formed by a mixture comprising a base forming the carrier portion and binder portion and PolyTetraFluoro-Ethylene (PTFE) forming the lubricant portion. The base of the coating material is available from s.a. GOVI n.v. of Belgium under the tradename LAGO 45 and is commonly used as a coating material for rope structures. Alternative products that may be used as the base material include polyurethane dispersions; in any event, the base material should have the following properties: good adhesion to fiber, stickiness, soft, flexible. The base of the coating material is or may be conventional and will not be described herein in further detail.

The example lubricant portion 34 of the coating material is a solid material generically known as PTFE but is commonly referred to by the tradename Teflon. The PTFE used in the coating material of the example rope structures 20a and 20b is in powder form, although other forms may be used if available. The particle size of the PTFE should be within a first preferred range of approximately 0.10 to 0.50 microns on average but in any event should be within a second preferred range of 0.01 to 2.00 microns on average. The example rope structures 20a and 20b are formed by a PTFE available in the marketplace under the tradename PFTE30, which has an average particle size of approximately 0.22 microns.

The coating material used by the example rope structures 20a and 20b comprises PTFE within a first preferred range of approximately 32 to 37% by weight but in any event should be within a second preferred range of 5 to 40% by weight, with the balance being formed by the base. The example rope structures are formed by a coating material formed by approximately 35% by weight of the PTFE.

As an alternative to PTFE, the lubricant portion 34 may be formed by solids of other materials and/or by a liquid such as silicon oil. Other example materials that may form the lubri-

cant portion 34 include graphite, silicon, molybdenum disulfide, tungsten disulfide, and other natural or synthetic oils. In any case, enough of the lubricant portion 34 should be used to yield an effect generally similar to that of the PTFE as described above.

The coating 26 is applied by dipping the entire rope structure 20a and/or individual strands 22 into or spraying the structure 20a and/or strands 22 with the liquid form of the coating material. The coating material is then allowed to dry on the strands 22 and/or rope structure 20a. If the coating 26 is applied to the entire rope structure 20a, the strands are braided or twisted before the coating material is applied. If the coating 26 is applied to the individual strands 22, the strands are braided or twisted to form the rope structure 20b after the coating material has dried.

In either case, one or more voids 36 in the coating 30 may be formed by absences of coating material. Both dipping and spraying are typically done in a relatively high speed, continuous process that does not allow complete penetration of the coating material into the rope structures 20a and 20b. In the example rope structure 20a, a single void 36 is shown in FIG. 1A, although this void 36 may not be continuous along the entire length of the rope structure 20a. In the example rope structure 20b, a void 36 is formed in each of the strands 22 forming the rope structure 20b. Again, the voids 36 formed in the strands 22 of the rope structure 20b need not be continuous along the entire length of the rope structure 20a.

In the example rope structures 20a and 20b, the matrix formed by the coating 30 does not extend through the entire volume defined by the rope structures 20a or 20b. In the example structures 20a and 20b, the coating 30 extends a first preferred range of approximately  $\frac{1}{4}$  to  $\frac{1}{2}$  of the diameter of the rope structure 20a or the strands of the rope structure 20b but in any event should be within a second preferred range of approximately  $\frac{1}{8}$  to  $\frac{3}{4}$  of the diameter of the rope structure 20a or the strands of the rope structure 20b. In the example rope structures 20a and 20b, the coating matrix extends through approximately  $\frac{1}{3}$  of the diameter of the rope structure 20a or the strands of the rope structure 20b.

In other embodiments, the matrix formed by the coating 30 may extend entirely through the entire diameter of rope structure 20a or through the entire diameter of the strands of the rope structure 20b. In these cases, the rope structure 20a or strands of the rope structure 20b may be soaked for a longer period of time in the liquid coating material. Alternatively, the liquid coating material may be forced into the rope structure 20a or strands of the rope structure 20b by applying a mechanical or fluid pressure.

The following discussion will describe several particular example ropes constructed in accordance with the principles of the present invention as generally discussed above.

#### First Specific Rope Example

Referring now to FIGS. 2, 3, and 4, those figures depict a first specific example of a rope 40 constructed in accordance with the principles of the present invention. As shown in FIG. 2, the rope 40 comprises a rope core 42 and a rope jacket 44. FIG. 2 also shows that the rope core 42 and rope jacket 44 comprise a plurality of strands 46 and 48, respectively. FIG. 4 shows that the strands 46 and 48 comprise a plurality of yarns 50 and 52 and that the yarns 50 and 52 in turn each comprise a plurality of fibers 54 and 56, respectively. FIGS. 3 and 4 also show that the rope 40 further comprises a coating material 58 that forms a matrix that at least partially surrounds at least some of the fibers 54 and 56.



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The exemplary rope core **42** and rope jacket **44** are formed from the strands **46** and **48** using a braiding process. The example rope **40** is thus the type of rope referred to in the industry as a double-braided rope. The strands **46** and **48** may be substantially identical in size and composition. Similarly, the yarns **40** and **42** may also be substantially identical in size and composition. However, strands and yarns of different sizes and compositions may be combined to form the rope core **42** and rope jacket **44**. Additionally, the fibers **44** and **46** forming at least one of the yarns **40** and **42** may be of different types.

## Second Rope Example

Referring now to FIGS. **5**, **6**, and **7**, those figures depict a second example of a rope **60** constructed in accordance with the principles of the present invention. As perhaps best shown in FIG. **6**, the rope **60** comprises a plurality of strands **62**. FIG. **7** further illustrates that each of the strands **62** comprises a plurality of yarns **64** and that the yarns **64** in turn comprise a plurality of fibers **66**. FIGS. **6** and **7** also show that the rope **60** further comprises a coating material **68** that forms a matrix that at least partially surrounds at least some of the fibers **66**.

The strands **62** are formed by combining the yarns **64** using any one of a number of processes. The exemplary rope **60** is formed from the strands **62** using a braiding process. The example rope **60** is thus the type of rope referred to in the industry as a braided rope.

The strands **62** and yarns **64** forming the rope **60** may be substantially identical in size and composition. However, strands and yarns of different sizes and compositions may be combined to form the rope **60**. In the example rope **60**, the strands **62** (and thus the rope **60**) may be 100% HMPE or a blend of 40-60% by weight of HMPE with the balance being Vectran.

## Third Rope Example

Referring now to FIGS. **8**, **9**, and **10**, those figures depict a third example of a rope **70** constructed in accordance with the principles of the present invention. As perhaps best shown in FIG. **9**, the rope **70** comprises a plurality of strands **72**. FIG. **10** further illustrates that each of the strands **72** comprises a plurality of yarns **74**, respectively. The yarns **74** are in turn comprised of a plurality of fibers **76**. FIGS. **9** and **10** also show that the rope **70** further comprises a coating material **78** that forms a matrix that at least partially surrounds at least some of the fibers **76**.

The strands **72** are formed by combining the yarns **74** using any one of a number of processes. The exemplary rope **70** is formed from the strands **72** using a twisting process. The example rope **70** is thus the type of rope referred to in the industry as a twisted rope.

The strands **72** and yarns **74** forming the rope **70** may be substantially identical in size and composition. However, strands and yarns of different sizes and compositions may be combined to form the rope **70**.

## Fourth Rope Example

Referring now to FIGS. **11**, **12**, and **13**, those figures depict a fourth example of a rope **80** constructed in accordance with the principles of the present invention. As perhaps best shown in FIG. **12**, the rope **80** comprises a plurality of strands **82**. FIG. **13** further illustrates that each of the strands **82** comprise a plurality of yarns **84** and that the yarns **84** in turn comprise a plurality of fibers **86**, respectively. FIGS. **12** and **13** also

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show that the rope **80** further comprises a coating material **88** that forms a matrix that at least partially surrounds at least some of the fibers **86**.

The strands **82** are formed by combining the yarns **84** using any one of a number of processes. The exemplary rope **80** is formed from the strands **82** using a braiding process. The example rope **80** is thus the type of rope commonly referred to in the industry as a braided rope.

The strands **82** and yarns **84** forming the rope **80** may be substantially identical in size and composition. However, strands and yarns of different sizes and compositions may be combined to form the rope **80**. The first and second types of fibers are combined to form at least some of the yarns **84** are different as described above with reference to the fibers **24** and **28**. In the example rope **80**, the strands **82** (and thus the rope **80**) may be 100% HMPE or a blend of 40-60% by weight of HMPE with the balance being Vectran.

Given the foregoing, it should be clear to one of ordinary skill in the art that the present invention may be embodied in other forms that fall within the scope of the present invention.

What is claimed is:

1. A rope structure adapted to engage an intermediate structure while loads are applied to ends of the rope structure, comprising:

a primary strength component comprising a plurality of fibers adapted to bear the loads applied to the ends of the rope structure;

a coating comprising

a lubricant portion formed by at least one of solids and liquids, and

a binder portion, where the binder portion is applied to the primary strength portion to form a matrix that at least partly surrounds at least some of the fibers to support the lubricant portion relative to at least some of the fibers; whereby

the matrix supports the lubricant portion such that the lubricant portion

reduces friction between at least some of the plurality of fibers, and

reduces friction between at least some of the plurality of fibers and the intermediate structures;

the coating material is applied to the primary strength component in liquid form and allowed to dry to form the coating; and

the liquid form of the coating material comprises substantially between 32% and 37% by weight of the lubricant portion.

2. A rope structure as recited in claim 1, in which the liquid form of the coating material comprises substantially between 5% and 40% by weight of the lubricant portion.

3. A rope structure as recited in claim 1, in which the liquid form of the coating material comprises approximately 35% by weight of the lubricant portion.

4. A rope structure as recited in claim 1, in which the binder portion adheres to the fibers such that the lubricant portion is arranged between at least some of the fibers and between at least some of the fibers and the intermediate structure.

5. A rope structure as recited in claim 4, in which the lubricant portion is in powder form.

6. A rope structure as recited in claim 1, in which the lubricant portion is formed by particles having an average size of within approximately 0.01 microns to 2.00 microns.

7. A rope structure as recited in claim 6, in which an average size of the particles is within approximately 0.10 microns to 0.50 microns.

8. A rope structure as recited in claim 6, in which an average size of the particles is approximately 0.22 microns.



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9. A rope structure as recited in claim 1, in which the binder portion adheres to at least some of the fibers.

10. A rope structure as recited in claim 1, in which the coating comprises a polyurethane dispersion.

11. A method of forming a rope structure adapted to engage an intermediate structure while loads are applied to ends of the rope structure, comprising the steps of:

providing a plurality of fibers;

combining the plurality of fibers to form a primary strength component adapted to bear the loads applied to the ends of the rope structure;

providing a coating material in liquid form comprising a lubricant portion and a binder portion, where the lubricant portion is formed by at least one of particles, where an average particle size of the particles is within approximately 0.01 microns to 2.00 microns;

applying the coating material in liquid form to the primary strength component;

allowing the coating material in liquid form to dry on the primary strength member such that the binder portion forms a matrix that at least partly surrounds at least some of the fibers to support the lubricant portion relative to at least some of the fibers such that the lubricant portion reduces friction between at least some of the plurality of fibers and between at least some of the plurality of fibers and the intermediate structure.

12. A method as recited in claim 11, in which the step of providing the liquid form of the coating material comprises the step of providing substantially between 5% and 40% by weight of the lubricant portion.

13. A method as recited in claim 11, in which the step of providing the liquid form of the coating material comprises the step of providing a binder portion that adheres to at least some of the fibers and holds the lubricant portion in place.

14. A method as recited in claim 11, in which the step of providing the liquid form of the coating material comprises the step of providing a binder portion comprising a polyurethane dispersion.

15. A rope structure adapted to engage an intermediate structure while loads are applied to ends of the rope structure, comprising:

a primary strength component comprising a plurality of fibers adapted to bear the loads applied to the ends of the rope structure, where the plurality of fibers are combined to form plurality of yarns, the plurality of yarns are

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combined to form a plurality of strands, and the plurality of strands are combined to form the primary strength component;

a coating comprising particles suspended within a matrix formed of binder material such that the binder fixes the particles relative to at least some of the fibers such that the particles reduce friction between at least some of the plurality of fibers and between at least some of the plurality of fibers and the intermediate structure; wherein the coating is formed by applying coating material in a liquid form to the primary strength component;

the liquid form of the coating material comprises substantially between 5% and 40% by weight of the lubricant portion; and

an average size of the particles is within approximately 0.01 microns to 2.00 microns.

16. A rope structure adapted to engage an intermediate structure while loads are applied to ends of the rope structure, comprising:

a primary strength component comprising a plurality of fibers adapted to bear the loads applied to the ends of the rope structure;

a coating comprising

a lubricant portion formed by at least one of solids and liquids, and

a binder portion, where the binder portion is applied to the primary strength portion to form a matrix that at least partly surrounds at least some of the fibers to support the lubricant portion relative to at least some of the fibers; whereby

the matrix supports the lubricant portion such that the lubricant portion

reduces friction between at least some of the plurality of fibers, and

reduces friction between at least some of the plurality of fibers and the intermediate structure; and

the lubricant portion is formed by particles having an average size of within approximately 0.01 microns to 2.00 microns.

17. A rope structure as recited in claim 16, in which an average size of the particles is within approximately 0.10 microns to 0.50 microns.

18. A rope structure as recited in claim 16, in which an average size of the particles is approximately 0.22 microns.

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